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Plasma Physics Division

June 1977

NAVAL RESEARCH LABORATORY
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In this report the high explosive DATB is evaluated for use in a nondestructive pulsed high pressure gas system. A test configuration is described which permits measurement of acceleration and velocity of a free piston driven at various pressures generated by detonating small DATB charges. Test results are described and applicability to the LINUS-O system is considered.

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PULSED HIGH PRESSURE GAS GENERATOR FOR THE LINUS-O SYSTEM

Introduction

The conceptual design of the LINUS-0 magnetic flux compression experiment called for a rotating cylindrical experiment chamber which included a large number of free-pistons in contact with a liquid metal liner material. Experiment operation would require that these pistons be propelled simultaneously such that the liquid metal is driven radially inward through ports into the experiment chamber in a time of one to two milliseconds.

Piston drive requirements called for a gas system operating at approximately 350 Kg/cm^2 (5K psi), capable of driving a plurality of 5 cm diameter pistons a distance of 5 cm in a time of approximately 1 msec, with a simultaneity of operation within 50 microseconds. Additionally, the entire system would be rotating at speeds up to 5000 rpm and at temperatures as high as 200°C. Although final experiment design has relaxed some of these specifications, the required gas system is still beyond state of the art and requires development and testing.

Gas systems which were considered for this application are shown in Table 1. As a result of this tabulation, a multiple firing chamber, high explosive-driven piston design was selected as most applicable and a series of tests were set up based on an explosive-driven valve design developed for use at Picatinny Arsenal.[1,5]

Picatinny Arsenal Explosive-Driven Valve

The Chemical Processing Technology Division at Picatinny Arsenal, in developing techniques for transporting molten H.E. between processing stations via pipelines, required a device which could reliably interrupt a detonation wave travelling at approximately 7600 m/sec

Note: Manuscript submitted June 2, 1977.

through the pipeline, in the event of an accidental explosion at any station along the line. Fig. 1 shows the valve configurations which was developed to satisfy this requirement.

The valve is seated in the pipeline such that molten H.E. flows through it. When sensors indicated that a detonation wave is propagating through the pipeline, a small explosive charge is initiated at the base of the valve, propelling it forward approximately 5 cm, to position a shock absorber in line with the detonating explosive, in a time of less than 2 msec. A phenolic shock insulator surrounds the valve propellant charge. This phenolic material is destroyed at each test, but attenuates the detonation shock sufficiently to protect all other valve components. Thus, for test purposes, valve components are reusable.

Valve operating parameters, shown in Table 2, are very similar to those defined for the LINUS-O piston drive, and our past experience with EBW (Exploding Bridge Wire) detonators during the development of the SUZY II Bank[2] shows that microsecond timing-synchronism of multiple explosive charges is easily attainable. Therefore, it appears that this design could readily be modified to meet the LINUS-O requirements.

<u>LINUS-O Explosive-Driven Piston Tests</u>

In the LINUS-O gas generating system, particulate matter resulting from the use of a shock absorber such as the phenolic used in the Picatinny valve would be undesirable, since it would necessitate a clean-up of all firing chambers after each operation. Consequently, a series of tests were conducted at NRL to determine the feasibility of using H.E. pellets detonated in a shock-attenuating free air volume, to produce pressures required for experiment operation. Test procedures and results are as follows:

1. Explosive charge

After consultations with explosives experts at NSWC, White Oak, and Picatinny Arsenal, the explosive DATB ($C_6H_5N_5O_6$) was selected[3] as most desirable for our tests. It is readily available with a 5% nylon binder, under the military designation PBXN4. In this form it can be pressed into explosive pellets of various density and sizes to facilitate testing. In addition, it has a melting point at 283°C, does not detonate when subjected to flame, is stable for storage, has low impact sensitivity (2 Kg drop hammer height > 360 cm for 50% probability of detonation) and is inexpensive (≈ $22/Kg) when comparted to other CHNO composition explosives.

Energy output upon detonation in a confined chamber is approximately 1200 cal./gm[4], with explosive by-products being water vapor, CO, CO_2, N_2, and a quantity of free carbon which depends upon available oxygen in the firing chamber.

For test purposes, pellets were cylindrical, having a length to diameter ratio of 1. Sizes were manufactured as follows:

Size (l x d)	Weight	Density
0.3" X 0.3" (.76 X .76 cm)	.539 gm	1.67 gm/cc
0.4 X 0.4 (1 X 1 cm)	1.398 gm	1.67 gm/cc
0.5 X 0.5 (1.27 X 1.27 cm)	2.736 gm	1.67 gm/cc

Reynolds RP80 detonators were used in all tests. They were available with either brass or nylon sleeves. Each contained 0.217 gm of PETN explosive.

Explosive charges were made by cementing various pellets sizes to a detonator using Eastman 910 cement. Charge sizes which were tested include: detonator only at 0.217 gm, detonator and one pellet at 0.81

gm, detonator and one pellet at 1.615 gm, detonator and one pellet at 2.935 gm, detonator and two pellets at 4.315 gm, detonator and two pellets at 5.689 gm.

2. Test Hardware

Figure 2 shows the test assembly used in evaluating H.E. as a gas generator. It is comprised of a thick-walled pressure vessel, a breech plug and piston.

The explosive chamber has a volume of 121 cm^3 which is divided between the breech plug and piston, thereby protecting the pressure chamber bore from damage due to high energy particles. Pressure seals are maintained using an O-ring on the breech plug and a combination of Viton O-rings and steel piston-rings on the piston. The payload includes the piston weighing 649 gm and a photography sleeve weighing 136 gm.

The explosive charge is supported by a thin metal tube which contains the detonator wires sealed in epoxy. The charge is positioned approximately at the center of the firing chamber.

The payload capture box is not shown, but consists of an 2.5 m long wooden structure filled with Vermiculite with a replaceable fiberboard window at the end. Thus the payload is captured without damage after each shot.

3. Diagnostics

Figure 3 shows the diagnostics arrangement used in obtaining acceleration and velocity measurements for the piston/photography-sleeve payload. The photography-sleeve rests against the piston, and protrudes 1/4 inch beyond the end of the pressure chamber allowing motion of the piston within the bore to be measured

A capacitor bank-powered spark-gap light source may be triggered either simultaneously or delayed with respect to the explosive charge initiation. It is focused to illuminate a transparent scale having 0.1 inch markings and positioned parallel with the payload flight path.

Motion of the photography-sleeve is recorded using a Beckman and Whitley model 326 high speed camera, operated at 72 microseconds per frame, with an effective shuttering speed of 5 microseconds.

Test Results

Multiple firings were conducted using both types of detonators in conjunction with each of the explosive charge increments previously described. Results were as follows:

1) Visual inspection revealed significant pitting of the firing chamber walls in the vicinity of the detonator. Pitting was greater with the brass sleeve detonator than with nylon.

2) A separate test was conducted in which firing chamber walls were shielded from detonator fragments but left exposed to the H.E. pellets. No damage was visible at the walls.

3) Figure 4 shows a typical set of curves for piston travel vs. charge mass. Measurements indicated that energy output varied between the two types of detonators, but variations became insignificant as pellet charges became much larger than detonator charges.

4) When explosive pressures were sufficient to overcome friction losses, but not so great as to deform the firing chamber, explosive pressure buildup is repeatable within system measurement accuracy. Fig. 5 shows a typical set of measurements.

5) A plot of velocity vs charge mass, m, (Fig 6) indicates that velocity increases proportional to $m^{\frac{1}{2}}$, within measurement accuracy.

6) Calculations based on an available detonation energy of 1200 cal./gm (Fig 7) show that system efficiency (piston kinetic energy/ available chemical energy) varies from 10% for small charges to 15% for larger charges. However, assuming a specific heat ratio, $\gamma = 1.2$, for the explosive gases and a maximum pressure chamber volume of 410 cm^3 before venting occurs, it is observed that the kinetic efficiency is approximately 60%.

7) Pressures generated by the 5.69 gram charge exceeded the 1050 Kg/ cm^2 (15K psi) strength of the firing chamber, resulting in a slight enlargement of the chamber and detonation gas blow-by past the piston seals.

Summary

Tests show that with careful design, high explosives may be used successfully in a fast, high pressure gas-generating system. Piston speeds of 100 m/sec are attainable with kinetic efficiencies exceeding 50%. The by-products of the explosion are gases and free carbon, so that only occasional cleanup of the pressure chamber should be necessary. By using modular explosive pellets, the total explosive charge can be readily tailored to meet particular experimental requirements. Such a system thus meets the requirements of the LINUS-0 experiment for an inexpensive, convenient source of pulsed high pressure gas.

Table 1

Linus O-Gas System Survey

	Static Pressure System	Gun Propellant	Rocket Propellant	High Explosives (DATB)
Sources of Information	Commercial catalogs, Engineering and Physics Texts	Technical discussions with Naval Surface Weapons Center, Herculese Powder, Olin-Winchester, Gun Propellant Texts	Thiokol Corp - inflatable airbag group, Herculese Powder-Posiedon Missile Gas Launch System	Picatinny Arsenal, Naval Surface Weapons Center, Explosives Effects Reports, Technical discussions with NSWC - Explosives Group
LINUS O Requirements:				
350 Kg/cm^2 pressure (5K psi)	NO Hardware such as pressure vessel, valves not available for required flow volume at specified pressure	YES Gun hardware design will handle 10K psi pressure buildup.	NO 350 Kg/cm^2 hardware feasible, but would require > $150K development cost	YES 350 Kg/cm^2 possible in gun type hardware. Must take care to design for shock overpressure.
piston movement: 5 cm (2 in.) in approx. 2 msec. with pressure buildup repeatability (jitter) less than 50 μsec.	NO Jitter and pressure repeatability requirements could not be met with available hardware.	NO Pressure buildup is too slow (≈ 20 msec)	NO Pressure buildup takes > 100 msec. Acceptable jitter time would require development of a triggered rupture disc.	EBW detonators allow detonation initiation in less than 1 μsec.
200°C operation	YES	NO Most gun propellant not stable at elevated temperature.	YES Rocket propellants readily available to this temp.	YES DATB is stable well above 200°C.
system operation to 5000 rpm	NO Not practical with available hardware.	NO Performance would be unpredictable due to g loading.	UNCERTAIN Chemicals O.K., but hardware size may be prohibitive	YES No obvious problem.
Safety	Hazardous. 350 Kg/cm^2 large gas system would be very difficult to use.	Relatively safe. Gun propellant handling techniques well developed.	Relatively safe. Propellants under consideration are non-explosive.	Relatively safe. DATB is one of the least sensitive high explosives.
Cleanliness	Presents no problem	Some cleanup required due to combustion products.	Presents no problem.	Some cleanup required from combustion products.
Cost	Prohibitive development costs	Conventional hardware. Cartridge and "per shot" costs high (> $40 X no. of pistons).	Development costs > $150K, "per shot"-cartridge costs ≈ $600.	"Per shot" costs approximately $5 x No. of pistons.

Table 2

Picatinny Arsenal Valve

	Protype valve	System valve
Valve Material	steel firing chamber, aluminum projectile	steel firing chamber, aluminum projectile
Valve Dimensions	5.08 cm X 10.16 long	7 cm dia. X 27.94 long
Valve Weight	.907 Kg	4.99 Kg
Explosive charge (includes detonator)	2 gms.	6.7 gms
Valve Travel	3.56 cm	6.35 cm
Valve operate time	< 1 msec	1.2 msec
Gas Seal	Viton O Ring	Viton O Ring
Gas Pressure (calculated	2.4 X 10^7 Kg/m^2 (35,000 psi)	2.4 X 10^3 Kg/cm^2 (35,000 psi)

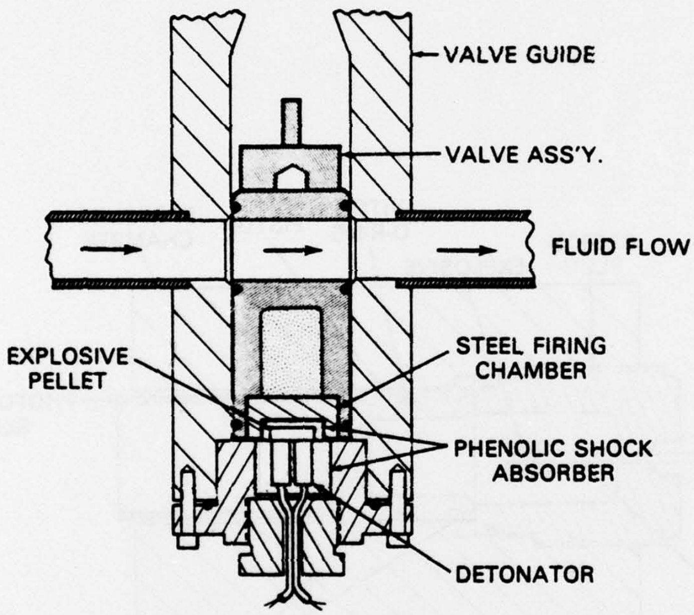

Figure 1. Picatinny Valve.

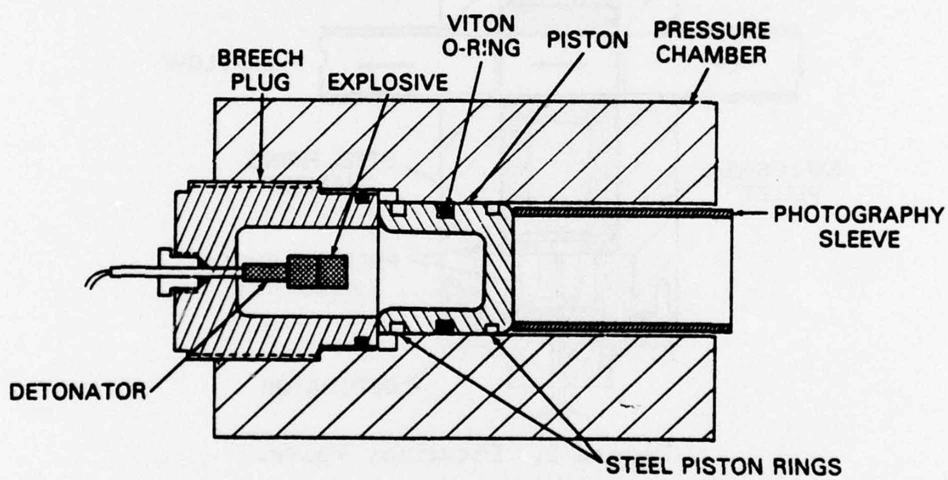

Figure 2. NRL - H. E. Driven Piston Test Assembly.

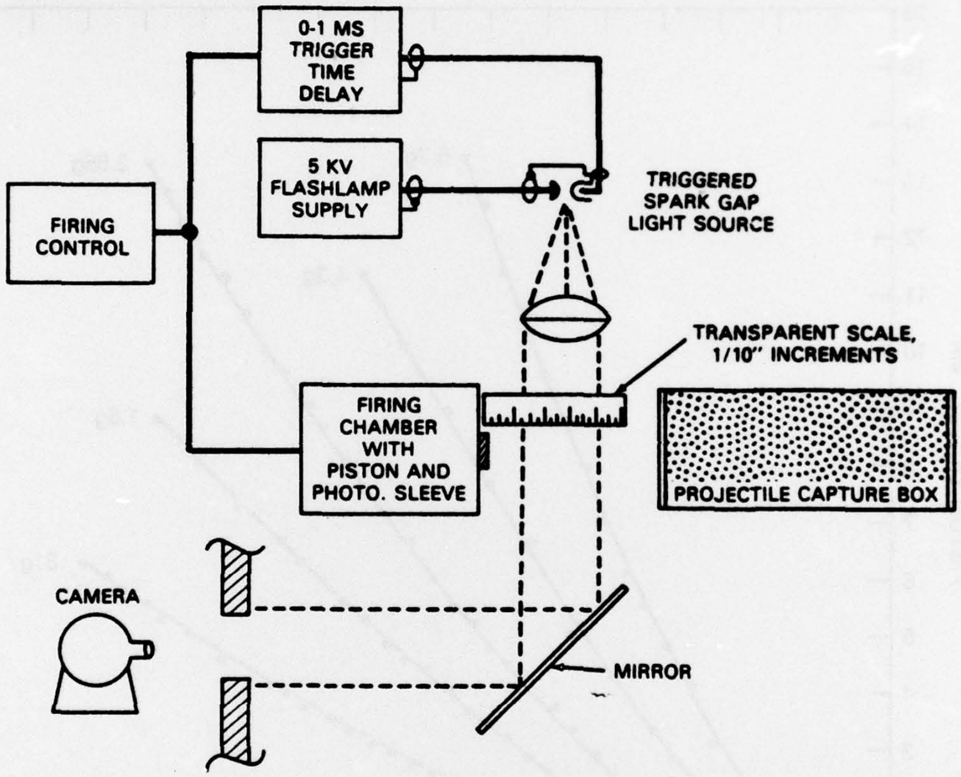

Figure 3. Schematic diagram of the diagnostic arrangement used for evaluating the high explosive gas generator performance.

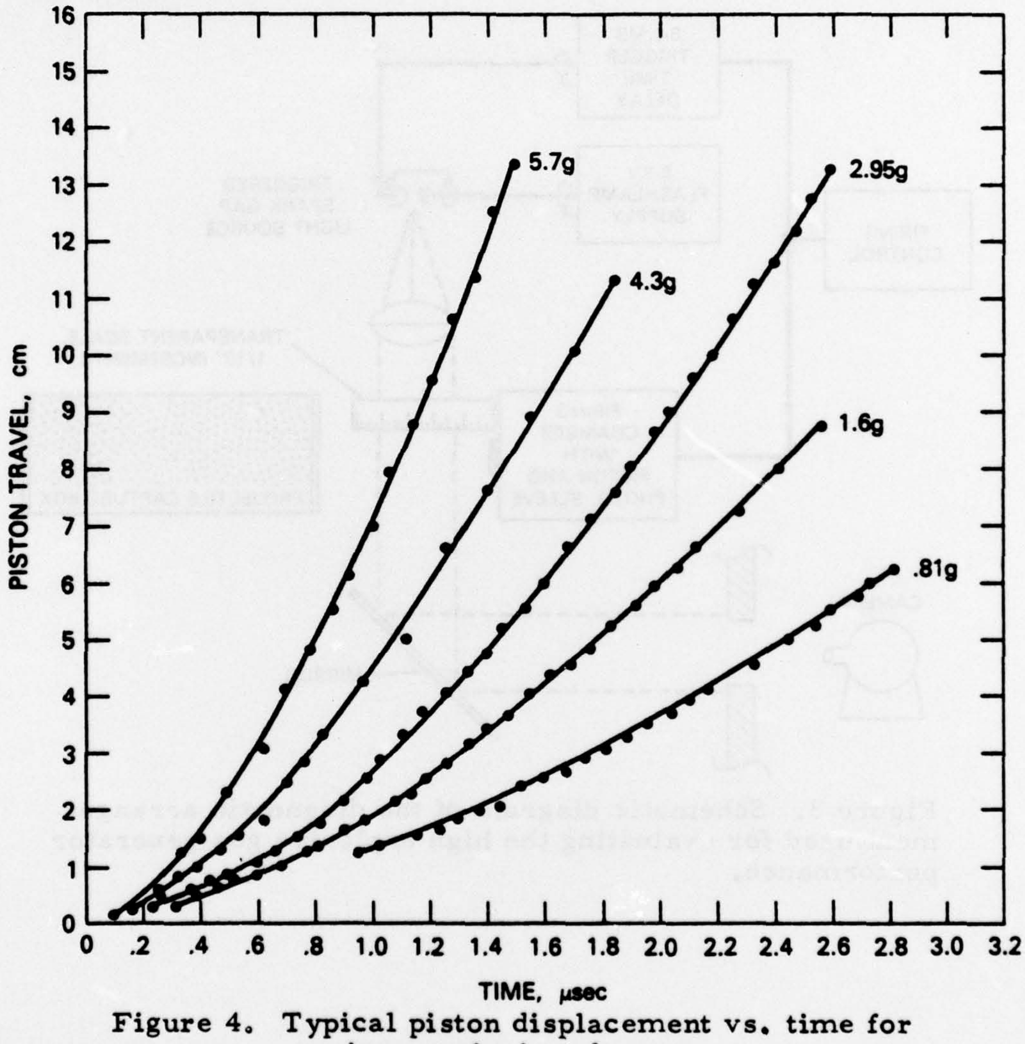

Figure 4. Typical piston displacement vs. time for various explosive charges.

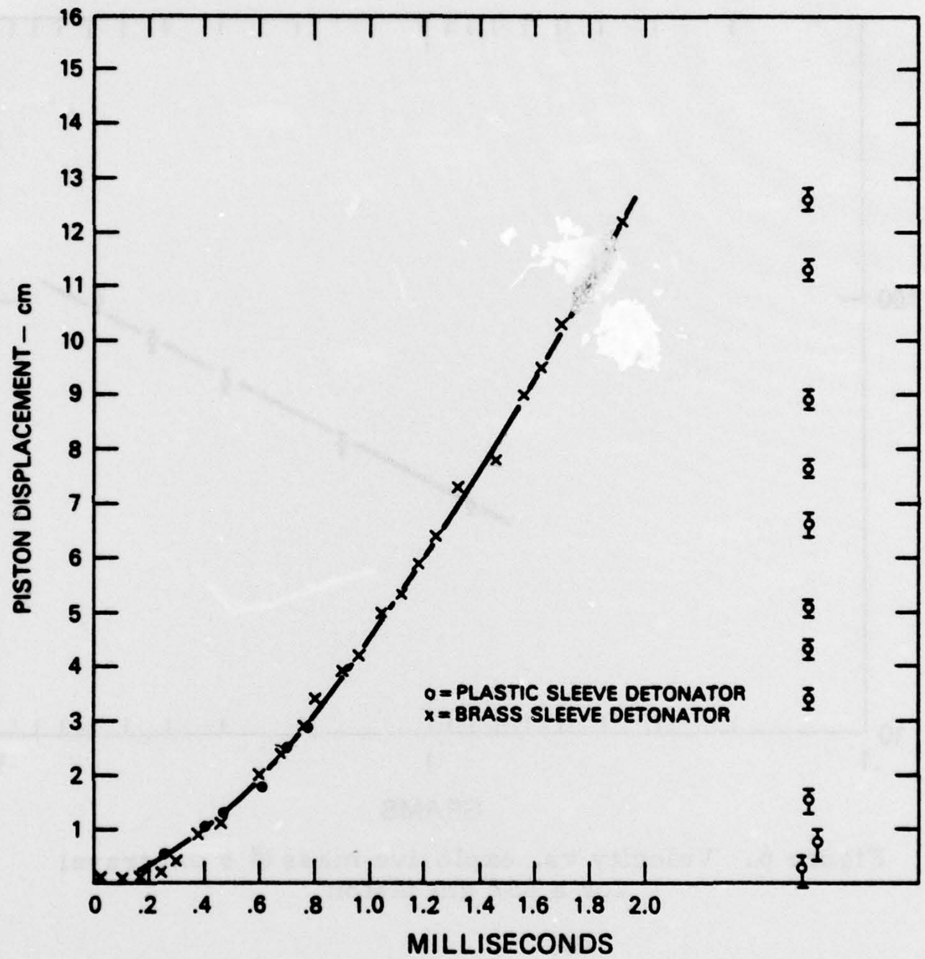

Figure 5. Piston displacement vs. time for 4.315 gm explosive charges.

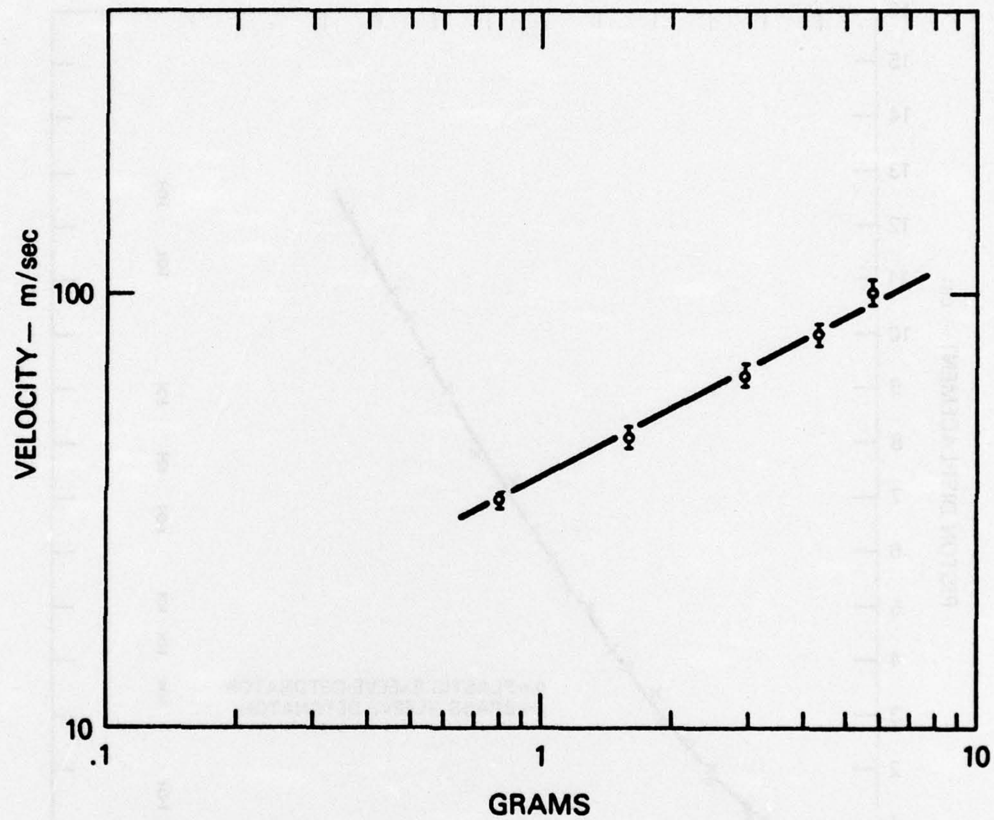

Figure 6. Velocity vs. explosive mass @ 6 cm travel for a 652 gm piston

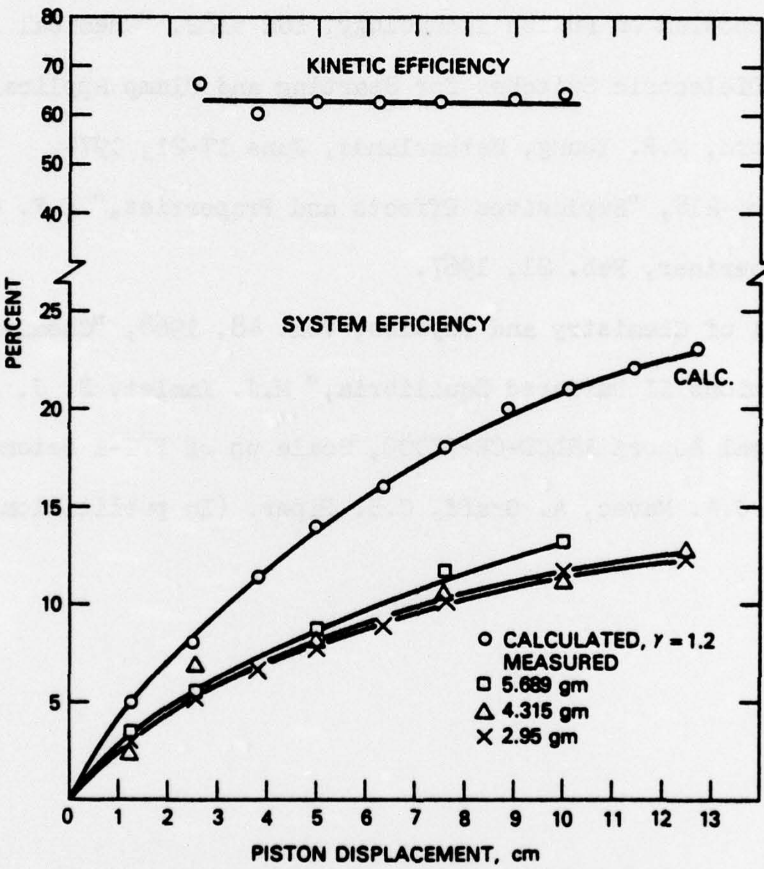

Figure 7. Linus O gas generator test assembly efficiency

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